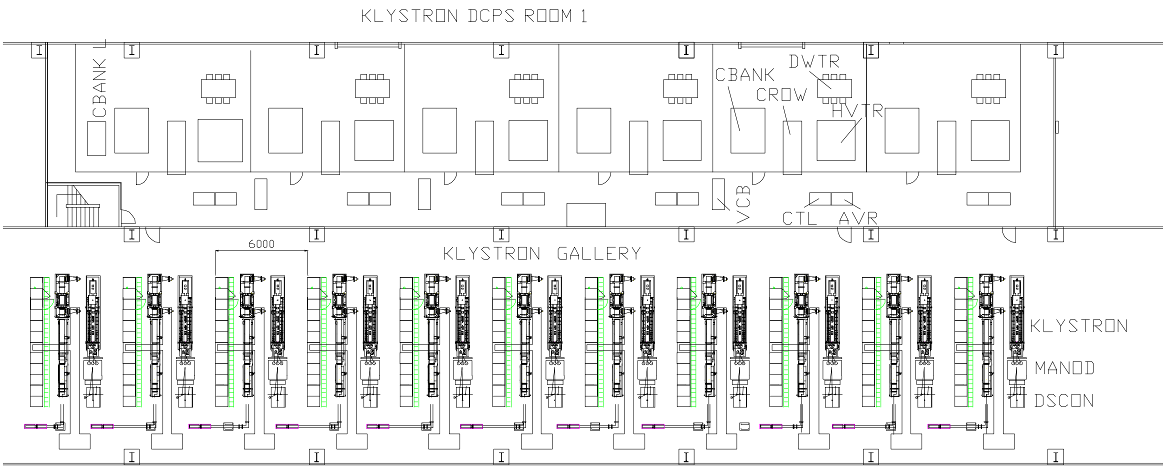
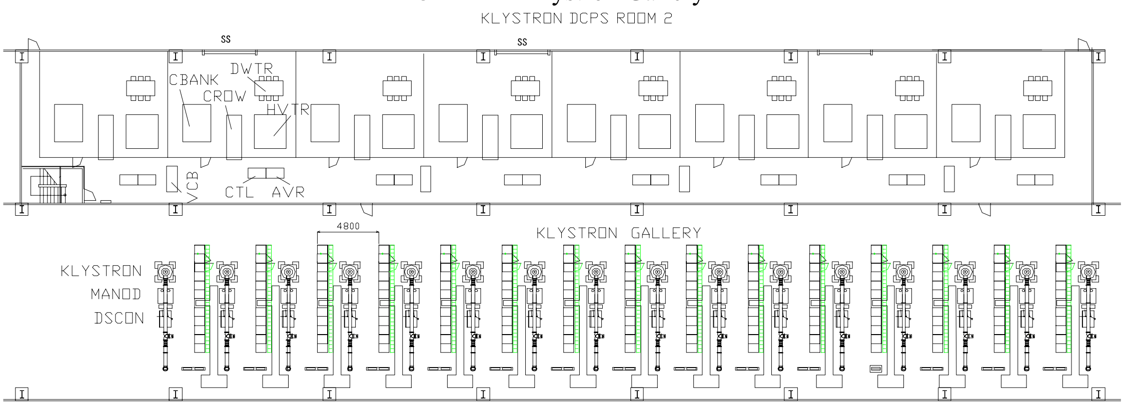
3.1.3.4 Klystron Power Supply

Layout of Klystron Power Supply System

Figure 3.1.3.4.1 shows the layout of the klystron power supply (KPS) systems for the 400-MeV proton linac. Five high-voltage (HV) dc power supplies (HVDC-1 to HVDC-5) feed the electric power to 20 klystrons for 324-MHz accelerating cavities (RFQ, DTLs, SDTLs) and six HV dc power supplies (HVDC-7 to HVDC-12) feed to 23 klystrons for 972 MHz accelerating cavities (ACS). Both types of klystrons require the almost same electric power (110kV, 45A) for generating 2.5 MW RF power (saturated at a working point), therefore, the principally identical KPS system will be installed. The buncher-3 and buncher-4 installed between the 324-MHz and 972-MHz accelerating sections and the debuncher-1 after the 972-MHz accelerating section require much less RF power for klystrons (670 kW and 250 kW), therefore, low power types of HV dc power supplies (HVDC-6 and HVDC-13: 80 kV, 30 A × 2) will be installed. These are summarized in Table-3.1.3.4.1.



324MHZ Klystron Gallery



972MHZ Klystron Gallery

FIG 3.1.3.4.1 Layout of klystron power supply system.

As shown in FIG 3.1.3.4.1, HV dc power supplies will be installed in rooms separated from the klystron gallery, so that the cable length connected between the HV dc power supplies and the klystrons becames to be an order of 100 m. In the conceptual design of the previous design report, we designed the system matched for this situation, and discussed about the feasibility of the klystron protection by the crowbar circuit [1]. The main parameters adopted in the HVDC design for the high power klystron are listed in Table-3.1.3.4.2.

Table 3.1.3.4.1 Number of HV dc power supplies and their types

HVDC type	No. of HVDC	No. of kly/HVDC	RF power/kly	No. of kly	Ib/kly
110kV, 180A	5	4	2.5 MW	20 (324MHz)	45 A
80kV, 60A	1	2	700 kW	2 (972MHz)	30 A
110kV, 180A	6	4	2.5 MW	23 (972MHz)	45 A
80kV, 60A	1	2	700 kW	1 (972MHz)	30 A

Table 3.1.3.4.2 Main parameters

Sag	Capacitance	Stored energy	Pulse width	Rep. rate	Duty
5 %	25.5 μF	154 kJ	700 μs	50 Hz	3.5 %

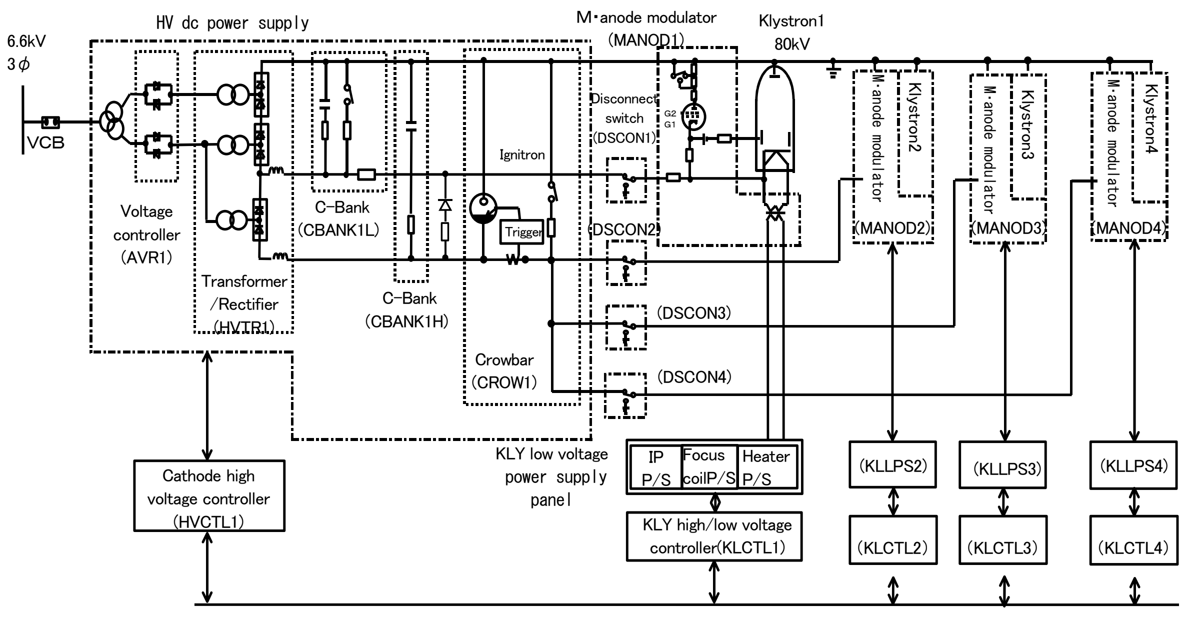


FIG 3.1.3.4.2 KPS system configuration of HVDC-1 (80-kV one port and 110-kV three ports).

Configuration of Klystron Power Supply System

The basic configuration of the klystron power supply system for high power klystrons consists of one HV dc power supply, four modulating anode (m-anode) modulators, and four sets of low voltage power supplies such as for a heater, an ion pump and focus coils. One HV dc power supply feeds the same voltage (Vk) to four klystron cathodes through their m-anode modulators, which generate the anode pulse voltage (Va) controlled separately. Thus the electric power for each klystron can be adjusted to the required power independently. In the first HV dc power supply (HVDC-1), one of the output ports supply the klystron for driving the RFQ (the required power is 680 kW), and other three output ports supplies three klystrons for DTL-1 to DTL-3 (the required power is about 2.5 MW). To keep the efficiency, the RFQ klystron is operated at a cathode voltage of 80 kV, and DTL klystrons at a cathode voltage of 110 kV. Figure 3.1.3.4.2 is shown the block diagram of this HVDC-1. When the crowbar is fired, the energy stored in the 80 kV c-bank also is absorbed by the crowbar circuit for the 110 kV power supply through a diode connected with both output ports.

M-Anode Modulator

The m-anode pulse voltage is generated by switching the cathode voltage through dividing resisters in the m-anode modulator. The anode voltage can be adjusted by the dividing ratio, and the pulse duration is controlled by switching device connected with the resistors in series. In consideration of the maintenance of the modulator, the semi-conductor switching device is adopted instead of the hard tube described in the previous design report [1].

The rise and fall time of the voltage pulse is several tens μs, and is subjected by a total capacitance (a few nF) of pulse-floated circuits including the output coaxial cable to the klystron oil tank. To shorten the rise and fall time, we design the dividing resistor value is about 100 kΩ. We adopted FET as a semi-conductor switching device rather than such as IGBT, because the required switching current is not so high (about 1 A). M-anode modulators have been worked without a serious trouble during 1000 hours or more.

Performance of Crowbar

The HV dc power supply is equipped with the crowbar circuit for protecting the klystron for the flash over event. We constructed five HV dc power supplies (HVDC-1 to HVDC-5) for the whole 324-MHz klystron system, and then installed and used two systems of them in the 60-Mev test linac. These showed the well performance of the crowbar protection. We realize the installation situation of the long distance configuration such as the layout of FIG 3.1.3.4.1, where the cable length between the HV dc power supply and the klystron are an order of 100m. Figure 3.1.3.4.3 is shown the equivalent circuit to consider about the crowbar work. The crowbar circuit is installed at the HVDC room for minimizing the pass loop of the crowbar current. In the crowbar circuit, the 5-series ignitron configuration is adopted. To absorb the stored energy in the coaxial cable that functions as a pulse forming network, the series resistor of 14Ω (Rs) is connected in the cathode voltage feed line. The wide Cu-plate grand line is laid along the coaxial cable to suppress bouncing of ground potential when the crowbar works.

The crowbar performance is tested using a fine Cu-wire of 0.3 mm in diameter and 200 mm in length instead of the klystron. The wire is used as a gauge that evaluates the energy absorbed into the klystron at discharge. We measured that the crowbar current flowing through the wire started at less than 6 μs after the crowbar switch was closed, and the wire did not melt. This phenomenon demonstrates the crowbar circuit properly protects the klystron.

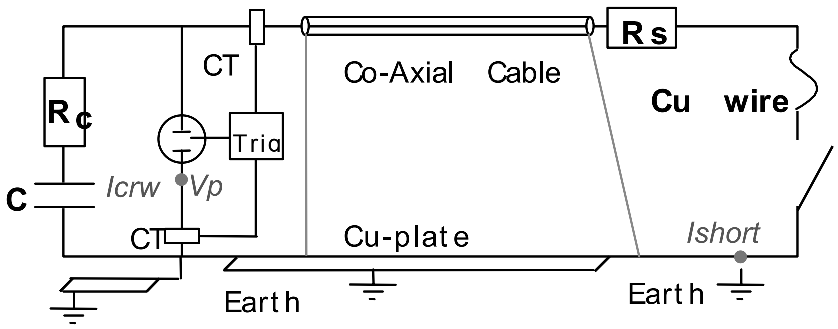


FIG 3.1.3.4.3 Equivalent circuit at crowbar working.

Performance of Klystron Power Supply System

At the normal operation of the klystron, the ground line is almost at the earth potential. Thus the performances or behaviors of the system components are well controlled and consistent with the estimations as discussed before. Figure 3.1.3.4.4 shows the typical performance of the present system. Even though some inconsistent measured quantities are recognized (insufficient calibration of a Va monitor), these measured waveforms show almost the required performance. Improvements of the interlock system for more safe operation are in our plan. The long-term stable operation with full loads (4 klystrons at the maximum working point) will indicate further refinements or modifications of the klystron power supply system.

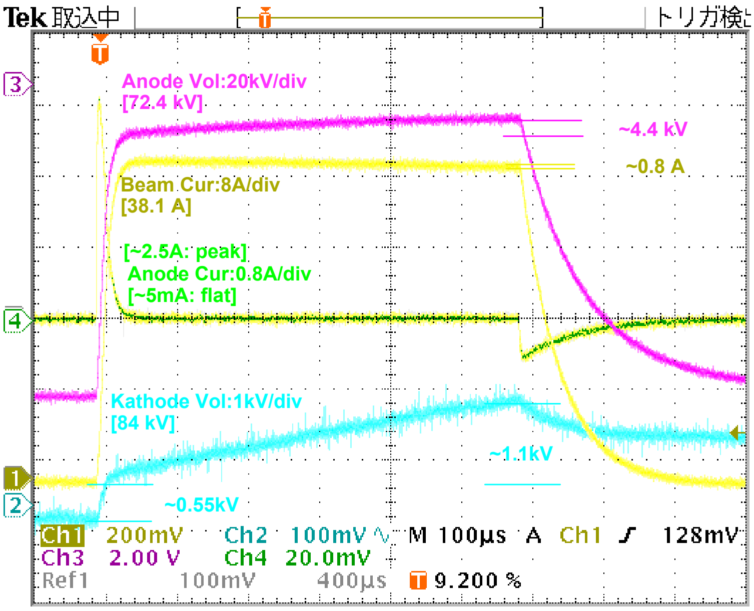


FIG 3.1.3.4.4 The pulse shapes of the anode voltage (Va), beam current (Ib), cathode voltage (Vk) and anode current (Ia). The voltage drop (0.55 kV) of Vk at pulse start is caused by a series resistance of 14 Ω at Ib of 38.1A. The sag (δVk=1.1 kV ~ 5%/4) is well consistent for 1 klystron load. The micro perveance ($\mu P = Ib / Va^{3/2} \times 10^{-6}$) measured at a flat region is 1.56. These indicate the system is working properly well for high power klystron operation.

References

[1] JHF Project Office, "JHF Accelerator Design Study Report", KEK Rep. 97-16 (JHF-97-10), 1998